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AXIAL DOUBLE POINT-LOAD TESTS ON SNOW AND ICE,(U)
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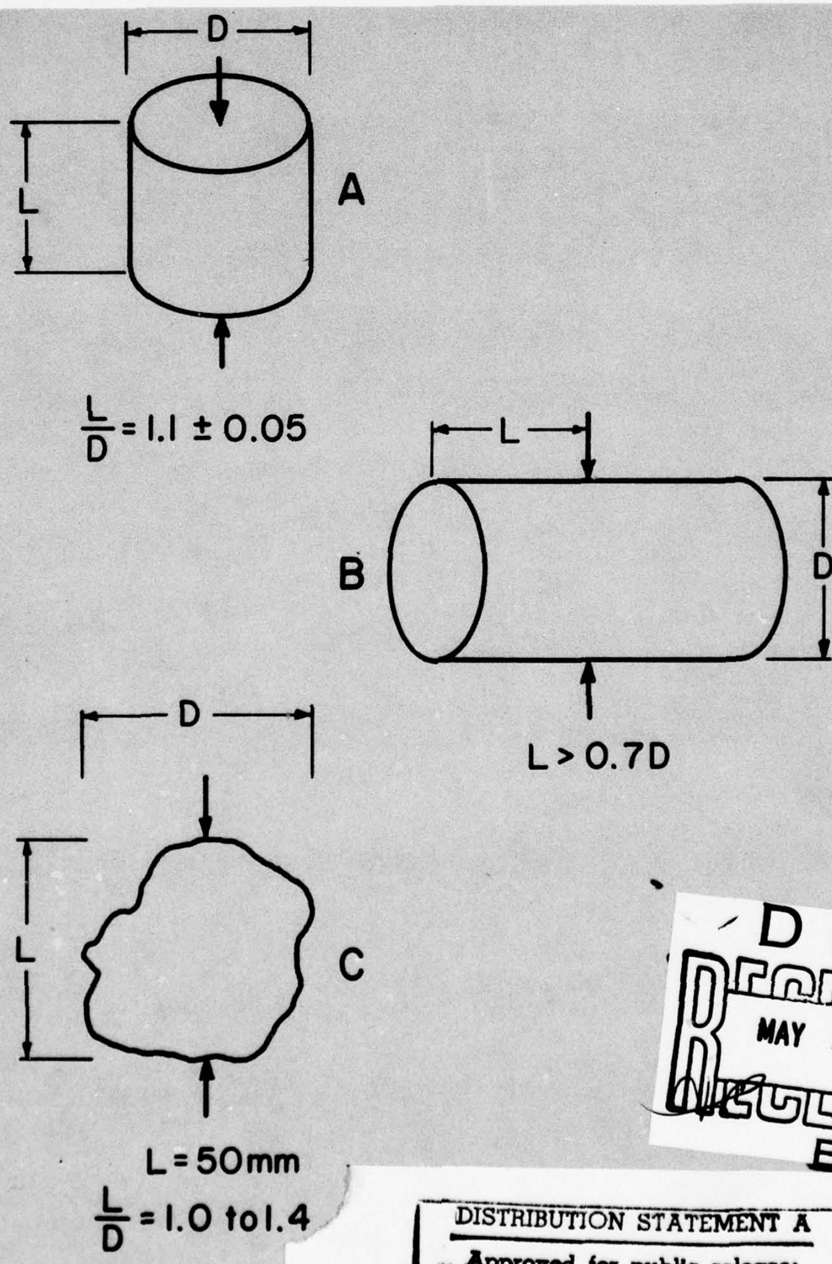
Axial double point-load tests on snow and ice



Cover: Sample shapes and loading configurations used in (A) axial, (B) diametral, and (C) irregular lump double point-load tests. The length (L)/ diameter (D) ratio for each test, as recommended by the Commission on Standardization of Laboratory and Field Tests of the International Society of Rock Mechanics, is also shown.

CRREL Report 78-1

Axial double point-load tests on snow and ice

Austin Kovacs

March 1978

Prepared for
DIVISION OF POLAR PROGRAMS
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The results of axial double point-load tests on disk samples of snow and ice obtained from the area of McMurdo Sound, Antarctica, are presented. They show the effects of temperature, sample length, load point diameter and specific gravity on failure load. It was determined that 13 samples should be tested to obtain a representative mean strength index. The results show that the axial double point-load test has good possibilities as a rapid field test for determining the unconfined compressive strength of snow and ice but that further evaluation of the variables affecting test results must be made.

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PREFACE

This report was prepared by Austin Kovacs, Research Civil Engineer, of the Foundations and Materials Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this study was provided by Grant DPP 74-23654 from the Division of Polar Programs, National Science Foundation.

Dr. Anthony Gow, Edwin Chamberlain, and Dr. Donald Nevel technically reviewed the manuscript of this report. The author gratefully acknowledges the assistance of Dr. Gow during sample collection and testing.

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AXIAL DOUBLE POINT-LOAD TESTS ON SNOW AND ICE

Austin Kovacs

INTRODUCTION

It is well recognized that sample preparation for axial unconfined compression and tension testing is difficult at best and that test results are extremely variable, depending upon the sample geometry and technique used. This recognition has recently been the subject of considerable discussion among researchers engaged in ice engineering. To help resolve some of these difficulties, the Committee on Ice Problems of the International Association of Hydraulic Research (IAHR) decided in January 1974 to form a subcommittee for the purpose of establishing standards specifically for testing the mechanical properties of ice (IAHR 1975).

In ice engineering, as in all structural engineering, material strength is an important fundamental property which must be considered in design analysis. A suitable strength index test which can give consistent and reliable values is therefore essential. Papers published since 1972 have aroused renewed interest in the point-load test as a convenient method for classifying rock strength. In principle it is a simple test, which can easily be performed in the field with lightweight, inexpensive equipment. And the resulting failure loads have been used to calculate the axial unconfined compressive or axial tensile strength of the rock material.

Broch and Franklin (1972) made a detailed study of the point-load test. They give the following empirical equation for determining the axial unconfined compressive strength of a cylindrical sample loaded diametrically to failure between two points (see cover):

$$\sigma_c = KI_s \qquad (1)$$

where σ_c = axial unconfined compressive strength
K = shape constant (used to convert I_s to σ_c)
I_s = diametral point-load strength index (= P/D^2)
P = failure load
D = sample diameter.

For the axial double-load test in which the load points are positioned at the center of each end of a right cylinder or disk (see cover), Broch and Franklin give the equation

$$\sigma_c = \frac{KP}{L^2} \qquad (2)$$

where L = sample length.

The axial tensile strength σ_+ may be determined (Peng 1976) from the latter test configuration by

$$\sigma_+ = \frac{KP}{\pi DL}\,. \qquad (3)$$

While this equation is in current use, Peng (1976) points out that it is an unvalidated approximation of the tensile strength. This is due in part to the equation having been developed for an axially point-loaded disk sample that is mathematically represented as an infinite elastic medium. As most materials undergo a certain amount of nonelastic behavior during testing, the above equations can be used only as a guide. Therefore, constants which allow the formulas to be used in predicting the axial compressive or tensile strength of materials need to be developed from test results.

Hoek (1977) suggests that Griffith's fracture theory indicates that the point-load test cannot be used to determine the tensile strength of soft material with an axial compressive/tensile strength ratio under 8. He further states that point-load testing of such material will normally give erratic results, even when the test is used as an index in its own right. Since the axial compressive/tensile strength ratio for ice is a function of

strain rate and is generally less than 8, it appears that the axial double point-load test may not be a suitable test for ice.

However, the apparent simplicity of the axial double point-load test, the limited sample preparation required, and the resultant short time needed between sample collection and testing are very attractive attributes. In addition, the test may prove to give a reliable strength index for ice and thus would be a practical field test for ice engineers. An evaluation of the test for determining the strength of snow and ice was therefore considered timely and important. Tests were made in January 1977 on snow and ice collected in the area of McMurdo Sound, Antarctica. The results of these tests are discussed in this report.

TEST PROCEDURE

The axial double point-load test method used in this study is a modification of one suggested by the Commission on Standardization of Laboratory and Field Tests of the International Society of Rock Mechanics (ISRM 1972). The test apparatus (Fig. 1) consisted of a small test frame, a hydraulic ram, a hand pump, a load cell, and an electric interface unit that provided a digital display of the peak force developed during a test. Fixed to the top of the ram and the bottom of the load cell were small steel balls, which served as the load points. An upright cylindrical sample was centered between these balls. When the ram was moved upward, axial point loading of the sample occurred. When the rupture strength of the material was reached, samples failed by splitting apart, usually into two or three columnar pieces. After the peak force was recorded on the digital display, the instrument was reset to zero for the next test by simply pressing a button.

The peak load recording system eliminated possible inaccuracies in the Bourdon pressure gage generally used in axial double point-load systems for measuring the peak hydraulic pump pressure developed during a test. This gage tends to have poor resolution because of its large pressure range. Also eliminated by this peak load recording system were any effects of seal friction in the hydraulic ram.

TEST PROGRAM

The purposes of the test program were to evaluate the effects of ice temperature, sample length and load point diameter on failure load. Snow was also tested to determine if there was a correlation between the axial double point-load test results and the axial unconfined compressive strength of snow of the same density (specific gravity). To achieve these goals over 250 samples were tested. Of these about 20 tests were rejected when the snow was crushed rather than split under the load points or when the ice spalled radially away from the load points.

TEST SAMPLES

Both snow and ice samples from Antarctica were tested. The snow specimens, obtained from the McMurdo Ice Shelf, varied from 0.61 to 0.73 in specific

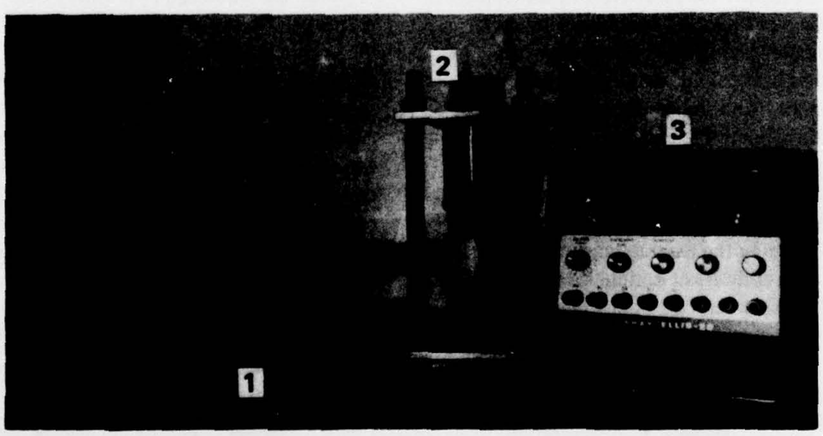
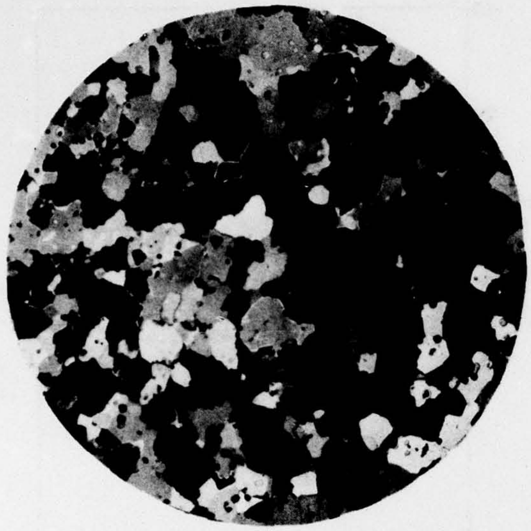


Figure 1. Axial double point-load system. From left to right: (1) hydraulic pump, (2) test frame with load cell (top), hydraulic ram (bottom) and test sample (center), (3) digital strain indicator.



a. Thin section of ice from Koettlitz Glacier.

b. Thin section of ice from Ross Island.

Figure 2. Representative thin sections of ice magnified ×1.2 from Koettlitz Glacier and Ross Island, Antarctica.

gravity. The ice samples came from an "ice wall" on Ross Island and from the floating tongue of the Koettlitz Glacier. A representative thin section of the ice from each site is shown in Figure 2. The ice from Ross Island was found to have air bubbles that were up to four times as large and ice crystals on the order of twice as large as the ice from the Koettlitz Glacier. The Koettlitz ice was found to be laced with very thin but healed fracture planes believed to be the result of thermal strianing. The specific gravity of the ice from Ross Island averaged 0.885 and that from the Koettlitz Glacier 0.895.

The samples, obtained with a CRREL auger, had a 76-mm (≃ 3-in.) diameter. They were cut on a band saw into right cylinders having lengths of 50, 78 or 100 mm (≃ 2, 3.1 or 3.9 in.). Sample length variation was limited to under 2 mm (≃ 0.1 in.) with the use of a cutting guide.

NUMBER OF TESTS FOR DETERMINING STRENGTH INDEX

The number of tests required to provide a representative mean failure strength or strength index for a material will vary with the material being tested as well as with the difficulty of performing a specific type of test. From an analysis of unconfined compression and Brazil tensile test results, Yamaguchi (1970) determined that 10 or more test samples are required to determine a statistically representative mean strength of rock. In the testing of snow and ice the author has attempted to use 15 or more samples (Kovacs et al. 1969, 1977).

To obtain some guidance on the number of axial double point-load tests which should be made on ice to obtain a representative mean strength index, 22 ice samples were tested. These samples were 76 mm (3 in.) in diameter and 78 mm (3.1 in.) long. They were tested at −14°C between 12.7-mm- (0.5-in.-) diam load points. The test failure loads along with the mean failure load and standard deviation beginning with the fifth test are listed in Table I. The data show that after the 12th test the mean failure load and the standard deviation varied insignificantly. Based on this result 13 samples were used in a given test series.

EFFECT OF TEMPERATURE

It has been inferred from the limited data available that the tensile strength of ice is not very sensitive to temperature variations (Hawkes and Mellor 1972) when the temperature range considered is on the order of −5° to −35°C. As the axial double point-load test is an indirect tensile test, it would follow that axial double point-load test results would likewise not be affected by temperature. To study the effect of temperature, axial double point-load tests were made on ice at −10°, −14° and −21°C. The results are listed in Table II and graphically presented in Figure 3. The slope of the line

Table I. Axial double point-load test results using 76-mm-diam, 78-mm-long samples of ice from Ross Island.

Samples were tested at $-14^{\circ}C$ with 12.70-mm-diam points.

Sample	Failure load (kg)	Failure load (lb)	Mean failure load (kg)	Mean failure load (lb)	Standard deviation (kg)	Standard deviation (lb)
1	220	484				
2	153	338				
3	192	423				
4	168	370				
5	220	485	191	420	30	66
6	158	349	185	408	30	66
7	194	428	186	411	28	61
8	226	498	191	422	29	64
9	137	303	186	409	33	72
10	242	534	191	421	35	78
11	160	353	188	415	35	77
12	145	320	185	407	36	79
13	195	429	186	409	34	76
14	171	376	184	406	33	73
15	179	395	184	406	32	70
16	181	399	184	405	32	70
17	245	541	187	413	33	73
18	162	357	186	410	33	73
19	142	314	184	405	34	74
20	219	483	186	409	34	74
21	151	332	184	405	34	74
22	217	474	185	408	34	74

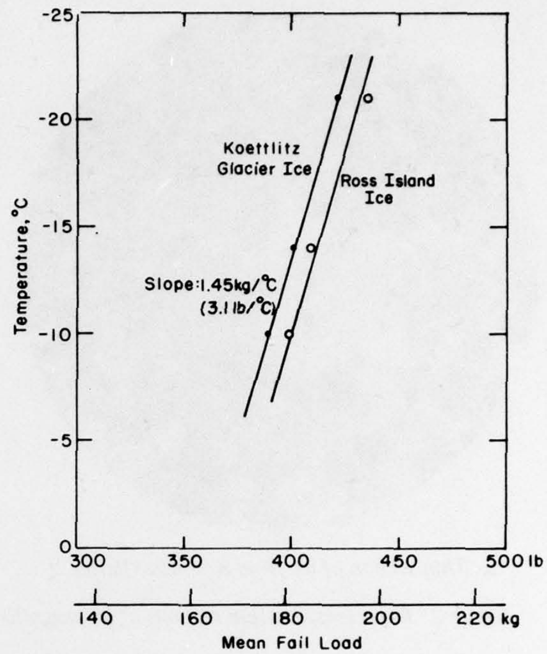


Figure 3. Temperature vs mean failure load for axial double point-load tests on ice from the Koettlitz Glacier and Ross Island.

Table II. Axial double point-load test results vs temperature.

Samples were 76 mm in diameter, 78 mm long and tested using 12.70-mm-diam load points.

Sample	Temperature ($-10^{\circ}C$) Failure load* (kg)	(lb)	Failure load† (kg)	(lb)	Temperature ($-14^{\circ}C$) Failure load* (kg)	(lb)	Failure load† (kg)	(lb)	Temperature ($-21^{\circ}C$) Failure load* (kg)	(lb)	Failure load† (kg)	(lb)
1	181	398	156	345	169	372	220	484	194	427	277	610
2	191	422	155	341	203	447	192	423	170	374	196	433
3	224	494	173	381	231	509	220	485	180	397	197	434
4	184	407	196	432	170	374	194	428	215	474	204	449
5	176	389	176	389	233	513	226	498	170	376	175	385
6	176	389	208	459	209	461	242	534	171	377	173	382
7	171	377	191	421	152	335	195	429	193	426	182	401
8	168	371	189	417	160	352	145	320	232	512	244	537
9	154	339	142	314	192	423	160	353	227	500	199	439
10	196	432	196	433	152	334	137	303	188	415	211	466
11	147	324	156	343	208	458	158	349	168	370	173	382
12	166	365	209	461	140	309	168	370	220	486	170	375
13	161	355	205	453	151	333	153	338	165	363	170	374
Mean	176	389	181	399	182	401	185	409	192	423	198	436
Standard deviation	20	44	23	50	32	70	34	76	24	53	32	70

* Koettlitz Glacier ice, 0.895 specific gravity.
† Ross Island ice, 0.885 specific gravity.

passing through the test data for each ice type is 1.45 kg/°C (3.1 lb/°C). This change in failure load vs temperature is equivalent to a tensile strength change of 0.20 kgf/cm^2 °C (2.85 psi/°C) or an unconfined compressive strength change of 0.65 kgf/cm^2 °C (9.3 psi/°C). Both these changes are significant.

Kovacs et al. (1977) have found from an analysis of published unconfined compressive strength vs temperature data that the unconfined compressive strength of ice changes at a rate of $\cong$ 0.75 kgf/cm^2 °C ($\approx$ 11 psi/°C). This shows that the failure strength of ice vs temperature noted in the axial double point-load test results is comparable with the change in the unconfined compressive strength vs temperature found by others.

The difference in failure load shown in Figure 3 between the ice from the Koettlitz Glacier and Ross Island is interesting. The finer-grained, higher density ice from the Koettlitz Glacier might have been expected to be stronger than the lower density Ross Island ice which had larger grains and larger, more irregular bubbles (see Fig. 2 and Coble and Parikh 1972). This was not the case. The difference noted is well inside the bounds of the standard deviation for each data set, suggesting that the difference is within experimental error. Nevertheless, the failure load difference may be due partly to a structural weakness in the Koettlitz ice associated with the very fine flaw seams previously discussed.

EFFECT OF SAMPLE LENGTH

As with the unconfined compression test, sample shape and size affect the axial double point-load test results. In this study cylindrical samples were used which had a constant diameter of 76 mm. This shape was selected out of convenience in that this was the inner diameter of the CRREL auger barrel used to obtain the samples. Inasmuch as this core barrel is widely used in glaciological and ice engineering studies, it is only reasonable that snow and ice samples for the axial double point-load test could become standardized as cylinders with this diameter.

Broch and Franklin (1972) determined empirically that a sample length/diameter ratio of about 1.1 ± 0.05 to 1 will give an axial double point-load strength index comparable to that obtained from a diametral double point-load test when the distance from the contact point and the nearest free end in the latter test is at least 0.7 D. As a result, this L/D ratio has been suggested as a standard by the International Society for Rock Mechanics (ISRM 1972). Broch and Franklin also showed that departure from an L/D ratio of 1.1 resulted in either a significant increase in the axial double point-load strength index (when the L/D ratio decreased) or a gradual decrease in the index (when the L/D ratio increased). The importance of maintaining a set sample length was clearly shown in their study.

Peng (1976) made a theoretical analysis of the axial double point-load test and found that the stress distribution in a test sample changes slightly when L/D > 1.33 and stabilizes when L/D < 1.00. He therefore concluded that the tensile fracture strength should not

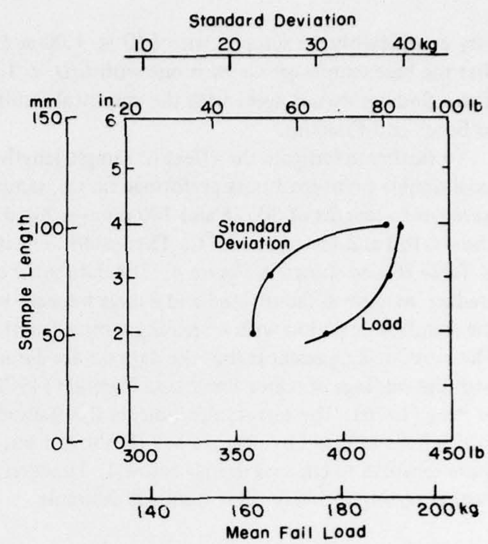


Figure 4. Effect of sample length on mean failure load for the axial double point-load test.

Table III. Axial double point-load test results vs sample length.

Koettlitz Glacier ice samples 76 mm in diameter were tested at −21°C using 12.70-mm-diam load points.

Sample	Length, 50 mm Failure load (kg)	(lb)	Length, 78 mm Failure load (kg)	(lb)	Length, 100 mm Failure load (kg)	(lb)
1	202	446	194	427	264	585
2	162	357	170	374	240	528
3	136	302	180	397	243	536
4	170	374	215	474	208	458
5	192	423	170	376	149	328
6	196	432	171	377	167	369
7	148	326	193	426	162	357
8	174	384	232	512	176	387
9	170	374	227	500	220	486
10	196	433	188	415	172	379
11	215	475	168	370	176	388
12	182	402	220	486	166	365
13	170	374	165	363	182	401
Mean	178	392	192	423	194	428
Standard deviation	22	49	24	53	37	81

vary considerably for samples with $L/D < 1.00$ and that the best sample geometry is one with $L/D < 1.00$. These findings do nc agree with the empirical results of Broch and Franklin.

To further investigate the effect of sample length on axial double point-load tests performed on ice, samples were cut to lengths of 50, 78 and 100 mm (≃ 2.0, 3.1 and 4.0 in.) and tested at -21°C. The results are listed in Table III and shown in Figure 4. The data show a gradual increase in failure load and a large increase in the standard deviation with increasing sample length. The most striking result is that the data do not agree with the findings of either Broch and Franklin (1972) or Peng (1976). The test results indicate that failure load is little affected by changes in L/D above 1 but quite sensitive to changes in L/D below 1. However, further testing to verify these results is desirable.

EFFECT OF LOAD POINT SIZE

The load point being recommended by the ISRM as a standard in the point-load testing of rock is a spherically truncated conical shape (ISRM 1972), with a 60° cone and a 5-mm (0.20-in.) tip radius. The selection of this size point was presumably based upon empirical test results; however, it is apparent that in certain "soft" materials the point will penetrate, and wedging by the walls of the cone will occur.

To avoid wedging and to determine the effect of point diameter on failure load, four spherical ball points with diameters of 4.70, 12.70, 15.88 and 25.40 mm (0.185, 0.500, 0.625 and 1.000 in.) were used (Fig. 5). The test results made on ice from the Koettlitz Glacier are listed in Table IV and shown in Figure 6. It was found that the 4.70-mm- (0.185-in.-) diam points would on occasion crush their way into the ice to a depth that allowed contact with the conical pedestal (Fig. 5). The resulting wedging by the pedestal was considered undesirable and these tests were discarded.

Failure load is shown to increase significantly with point diameter, reaching an apparent maximum at a point diameter of 25.4 mm (1 in.). The standard deviation was also found to increase appreciably with increasing point diameter. This may be due to a tendency of the ice samples to translate laterally a slight amount during seating of the largest balls. This would result in off-center nonaxial point loading, lower failure loads and thus a larger scatter in the test results. Thus the apparent peaking of the failure load and the accelerated increase in the standard deviation noted in the test results with the use of the 25.40-mm-diam load points may have been associated with nonaxial point loading. Further tests must be made to evaluate this.

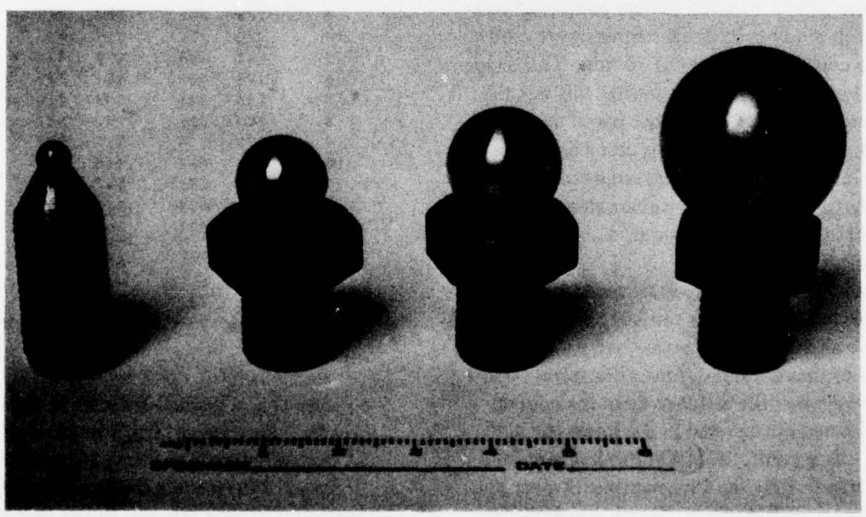


Figure 5. Configuration of the four ball points used in the axial double point-load tests.

Table IV. Axial double point-load test results vs point diameter for Koettlitz Glacier ice samples (76 mm in diameter, 78 mm long and tested at -21°C).

Sample	*Failure load** (kg)	(lb)	*Failure load†* (kg)	(lb)	*Failure load*** (kg)	(lb)	*Failure load††* (kg)	(lb)
1	113	249	194	427	227	500	316	696
2	107	235	170	374	191	420	220	486
3	95	209	180	397	214	471	342	754
4	104	230	215	474	218	480	191	421
5	89	197	170	376	236	521	200	442
6	105	231	171	377	175	385	193	426
7	116	256	193	426	248	547	199	439
8	89	197	232	512	270	595	163	359
9	82	182	227	500	230	506	197	435
10	100	220	188	415	186	409	219	482
11	131	288	168	370	211	466	164	361
12	101	222	220	486	185	407	259	571
13	107	236	165	363	190	418	240	528
Mean	103	227	192	423	214	471	223	492
Standard deviation	13	28	24	53	28	62	54	119

* Point diameter 4.70 mm (0.185 in.)
† Point diameter 12.70 mm (0.500 in.)
** Point diameter 15.88 mm (0.625 in.)
†† Point diameter 25.40 mm (1.000 in.)

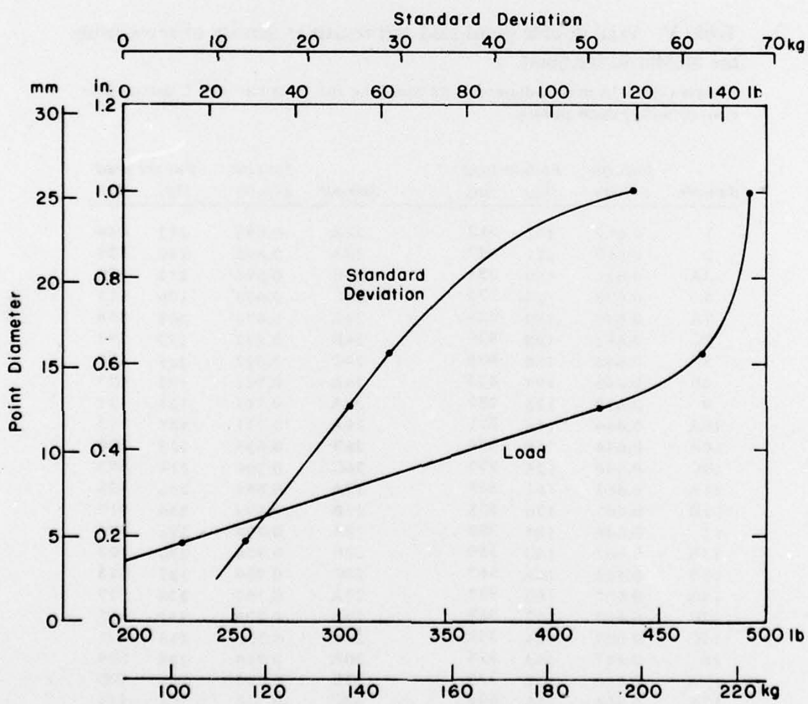


Figure 6. Effect of load point diameter on the axial double point-load test mean failure load. Results are from tests on ice samples.

TESTS ON SNOW

Over 70 axial double point-load tests, all using the 12.7-mm- (0.5-in.-) diam load points, were made on snow at –21°C. It was found that below a specific gravity of 0.61 the points would crush into the snow without splitting the sample in two. These tests were discarded. Some penetration by crushing also occurred in samples with a specific gravity as high as ≃ 0.65, but splitting of these samples would always follow. These test results were retained and are included with the test data given in Table V.

No unconfined compressive strength tests were made on the snow from the McMurdo ice shelf. However, unconfined compressive strength tests were made on similar density snow in Greenland (Kovacs et al. 1969), permitting a relatively close comparison. Since the uniaxial unconfined compressive strength of the Greenland snow samples was determined at –25°C, the axial double point-load failure loads listed in Table V were corrected to –25°C using the temperature correction factor previously determined in this report. The corrected data are shown in Figure 7. The curve passing through the data represents the Greenland axial unconfined compression test results.

It was expected that the axial double point-load test results would follow an exponential increase in failure load with increasing snow density similar to that observed for the axial unconfined compression tests. However, it was not expected that the double point-load test results would straddle the curve representative of the unconfined compressive strength of the Greenland snow. The cause of this virtual one-to-one correlation is a mystery – after all, one is a compressive test and the other an indirect tensile test. Whether this correlation could be maintained over the full density range of snow simply by changing to a larger point diameter below a specific gravity of 0.61 is, of course, unknown. It would be desirable to explore this further. Unfortunately, the ideal place to compare snow samples of varying density, the Inclined Drift at Camp Century, Greenland, is buried under a thick layer of new snow and is no longer accessible. In this drift an unlimited supply of snow or ice samples of any density could have been

Table V. Axial double point-load test results vs density of snow from the McMurdo Ice Shelf.

Samples were 76 mm in diameter, 78 mm long and tested at –21°C using 12.7-mm- (0.5-in.-) diam points.

Sample	Specific gravity	Failure load (kg)	Failure load (lb)	Sample	Specific gravity	Failure load (kg)	Failure load (lb)
1	0.613	142	312	22A	0.690	213	469
2	0.610	121	267	23A	0.696	240	529
3A	0.626	150	331	23B	0.696	222	489
5	0.638	124	274	23C	0.696	186	411
7A	0.639	153	338	24A	0.697	208	458
7C	0.652	198	436	24B	0.697	179	395
8A	0.648	184	405	24C	0.697	225	497
8B	0.648	196	433	26A	0.711	192	423
9	0.658	128	282	26A	0.711	187	413
10A	0.644	146	321	26A	0.711	187	413
10B	0.644	178	394	26B	0.696	222	490
10C	0.644	126	277	26C	0.700	214	473
11A	0.662	161	355	27A	0.694	206	454
11B	0.662	170	375	27B	0.694	234	515
12	0.644	181	399	28A	0.704	222	490
13A	0.662	163	359	28B	0.704	230	507
13B	0.662	166	367	28C	0.704	187	413
15A	0.667	160	352	29A	0.703	234	517
15B	0.667	167	369	29B	0.703	212	467
15C	0.667	161	355	29C	0.703	214	471
16	0.657	142	314	30A	0.714	238	524
17A	0.666	171	378	30B	0.714	181	400
17A	0.666	226	498	30C	0.714	186	411
17B	0.663	182	402	31A	0.715	191	421
17B	0.663	184	406	31B	0.715	178	393
18	0.682	228	502	32A	0.727	205	453
19A	0.671	217	478	32B	0.727	196	433
19B	0.671	271	479	33A	0.714	224	493
19B	0.671	194	429	33B	0.714	190	419

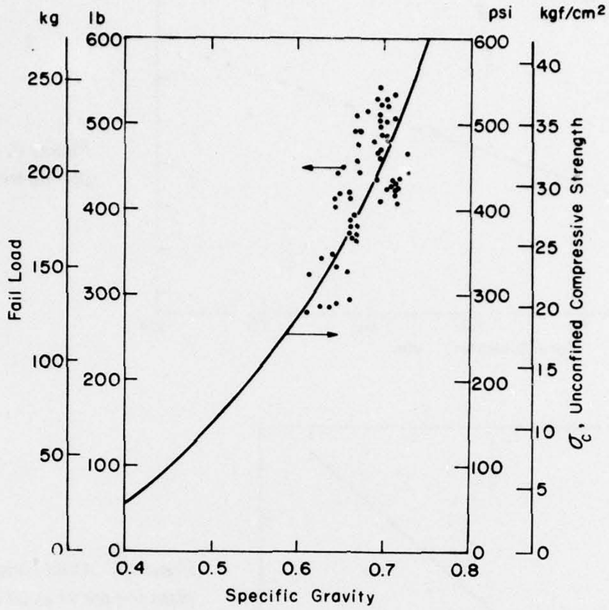


Figure 7. Axial double point-load test results on snow (dots) vs the unconfined compressive strength of snow (solid line) at –25°C.

obtained, and because the axial unconfined compressive strength vs density of the snow and ice in the drift has already been determined (Kovacs et al. 1969) it would have been very convenient to compare these strengths with axial double point-load test results.

DISCUSSION

The shape constant K in eq 1-3 is used to convert the axial double point-load strength index I_s to either the axial unconfined compressive or tensile strength. The appropriate value of K is dependent upon the diameter of the core tested. Bieniawski (1975) compared the axial unconfined compressive strength of rock with the point-load strength index obtained from the testing of cores 21.5, 42 and 54 mm in diameter. From his data a plot of the shape constant vs core diameter has been constructed in Figure 8. When the line passing through the test data is extended, a representative K value for the 76-mm-diam core tested in this study would appear to be 27.

To determine if this shape constant is an appropriate one for ice and if the axial double point-load test can be used to predict its axial unconfined compressive strength, a comparison was made between the strength calculated from eq 2 for the Ross Island ice and the axial unconfined compressive strength determined by Kovacs et al. (1969) on ice of a similar density. The Koettlitz ice tests were not used because of the internal flaw seams noted, which may have affected the test results. Results from axial double point-load tests made on 78-mm-long ice samples were selected because they gave an L/D ratio of 1.04 to 1, which is close to the 1.1 to 1 ratio suggested as a standard for axial double point-load test samples by the International Society of Rock Mechanics (ISRM 1972). Using the axial double point-load test failure load (extrapolated to –25°C) of 201 kg (444 lb) from Figure 3, an axial unconfined compressive strength of 89.2 kgf/cm² (1268 psi) was obtained from eq 2. For ice of the same specific gravity (0.885) and temperature (–25°C), Kovacs et al. (1969) obtained, from tests on 210-mm-long and 76-mm-diam core, an axial unconfined compressive strength of 91.1 kgf/cm² (1296 psi). There is virtually no difference (about 2%) between the two strengths.

Using eq 3, the calculated axial tensile strength for the Ross Island ice at –25°C is 28.8 kgf/cm² (410 psi). The resulting calculated axial unconfined compressive/tensile strength ratio is 3.1 to 1. This ratio is an artifact of eq 2 and 3. It will change only if sample length or diameter change.

Hawkes and Mellor (1972) and Haynes* (unpublished data) have shown that the tensile strength of ice

* F.D. Haynes, Materials Research Engineer, CRREL.

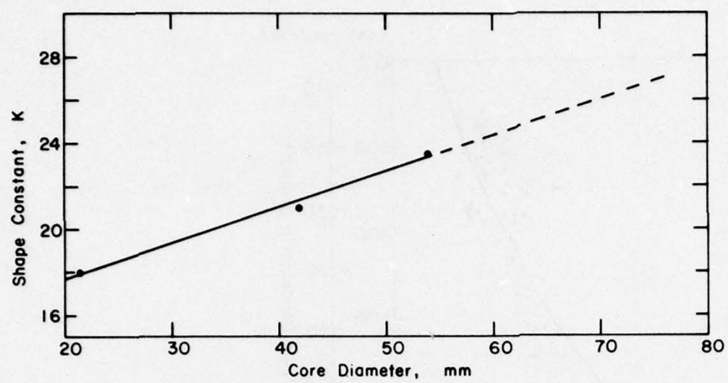


Figure 8. Shape constant vs test sample diameter.

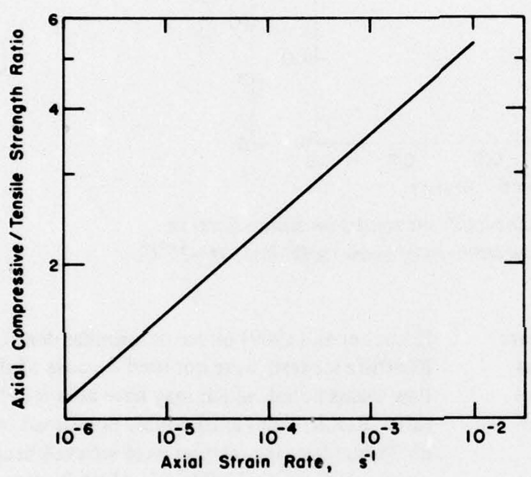


Figure 9. Axial compressive/tensile strength ratio for ice vs axial strain rate.

is virtually unaffected by strain rates between 10^{-6} and 10^{-2} s^{-1}, but that the axial unconfined compressive strength is highly affected by strain rate. A plot of the axial unconfined compressive/tensile strength ratio vs axial strain rate was constructed using their data. As shown in Figure 9 there is an exponential increase in the axial compressive/tensile strength ratio with increasing strain rates.

Figure 9 indicates that the axial compressive/tensile strength ratio of 3.1 to 1 found above should be representative of ice tested in direct compression and tension at a strain rate of $\simeq 7.0 \times 10^{-4}$ s^{-1}. This is indeed interesting, as the ice samples tested by Kovacs et al. (1969) were loaded at a strain rate of $\simeq 3.0 \times 10^{-3}$ s^{-1} – a difference of only 3.0×10^{-4} s^{-1}. This was fortuitous and is perhaps a reason for the exceptional agreement between the axial compressive strength and double point-load test results. Shape and size effects between the axial unconfined compression and axial double point-load test samples also contributed in some unique way to the agreement found in the strength values. In any event the comparison is very encouraging and indicates that further evaluation of the axial double point-load test on ice samples is warranted.

The usefulness of the axial double point-load test on snow samples remains to be determined. The limited snow test results presented are encouraging but also confusing. They are encouraging in that there is an exceedingly good correlation between the failure load obtained from the axial double point-load test and the related axial unconfined compressive strength for similar density snow. However, the reason for this correlation is not known, since the axial double point-load test is an indirect tensile test, not a compressive test. The failure load for these tests was nearly equal to the tensile strength calculated from eq 3. Therefore, the correlation was essentially between tensile failure loads and compressive strengths and not between two compressive strengths.

RECOMMENDATIONS

Many more tests must be made to determine the value of the axial double point-load test in ice engineering. The effect of temperature on test results, especially above -10°C, needs to be determined. It is believed that the effect of strain rate on axial double point-load test results is negligible because the test is an indirect tensile test. This belief is based on the work of Hawkes and Mellor (1972), who show that the tensile strength of ice is essentially unaffected by a change in strain rate between 10^{-6} and 10^{-2} s^{-1}. Nevertheless, this should be verified for axial double point-load tests on ice and snow. The effect of nonaxial point loading needs to be determined, and if found to be a serious problem, sample alignment guides will have to be incorporated into the test apparatus.

From the results of this study it is recommended that test samples have an *L/D* ratio of 1.1 ± 0.05 to 1. This ratio conforms with that suggested as a standard by the International Society of Rock Mechanics (ISRM 1972). Test samples should be standardized at 76 ± 1 mm (3.0 ± 0.1 in.) in diameter. This is the diameter of core taken by the CRREL auger, which is widely used by ice engineers and glaciologists.

The best ball point diameter for axial double point-load testing of ice has not been conclusively determined. However, it is recommended at this time that 15-mm-(0.6-in.-) diam ball points be used. Smaller points may result in undesirable crushing and penetration into warm or low density ice and into snow. For snow with a specific gravity below 0.61, ball points on the order of 40 mm in diameter may be necessary to avoid ball crushing penetration into the material.

In these tests it was determined that 13 or more samples should be tested to obtain a statistically representative mean failure strength. In no case should less than 10 samples be tested.

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In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

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Bibliography: p.11.
1. Ice. 2. Ice strength. 3. Loads(forces) 4. Snow. I.United States. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H. II. Title III. Series

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